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*Avionics Division*

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# RESEARCH & DEVELOPMENT (R & D) STATUS REPORT

# ADVANCED MATERIALS PARTNERSHIPS

**CONTRACT: N00014-96-C-0171**

**CDRL ITEM: A001**
**Submission: 00-Q-05**
**December 2001**

**PREPARED FOR:**

**Advanced Research Projects Agency (ARPA)**
**Defense Sciences Office**
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# ARPA ADVANCED MATERIALS PARTNERSHIP
# R&D PROGRAM STATUS REPORT
# December 2001

**ARPA ORDER:** 96PR05003-00
97PR04664-00 (Amendment)

**PROGRAM CODE:** S310A
D0C9(T)

**CONTRACTOR:** ITT DEFENSE & ELECTRONICS
ITT AVIONICS DIVISION
With major subcontracts to:
BRUSH WELLMAN INC. ENGINEERED MATERIALS
RAYTHEON TI SYSTEMS

**CONTRACT AMOUNT:** $2,197,959

**CONTRACT:** N00014-96-C-0171

**EFFECTIVE DATE OF CONTRACT:** 9/17/96 and 6/27/97 (high strength casting amendment)

**EXPIRATION DATE OF CONTRACT:** 10/31/01

**PRINCIPLE INVESTIGATOR:** Steven V. Axelband

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**WORK DESCRIPTION:**

Manufacturing process development for Beryllium-Aluminum (AlBeMet) and Beryllium-Beryllium Oxide (E-Material) alloys for avionics applications.

**REPORTING PERIOD:**

March 1999 through December 2001

**DESCRIPTION OF PROGRESS:**

Processes have been successfully developed for the manufacture of structures and assemblies from AlBeMet and E-Material to support electronic systems.

These processes have been applied in the Army Suite of Integrated Electronic Countermeasures (SIRFC) system. The system has been qualified and flight-tested with AlBeMet structures.

Manufacturing processes have also been developed for high strength AlBeMet casting and have been applied in test structures for a Raytheon Forward Looking InfraRed (FLIR) system.

This program has significantly contributed to a meaningful increase in the infrastructure supporting fabrication capabilities with Beryllium composites.

**Conferences and meetings:** Nothing to report

**Machined and brazed AlBeMet** versions of the SIRFC LRU-1 (Receiver-Processor), LRU-2 (Transmitter), LRU-3 (Modulator) and LRU-4 (Antenna group) structures and electronic modules have been fabricated, assembled and extensively tested. Environmental screening and qualification testing and extensive engineering tests have proven the suitability of AlBeMet as a lightweight structural material for electronic systems. Attached is an **Engineering Environmental Test Report** for vibration tests performed on a brazed SIRFC LRU-1 chassis. The SIRFC system constructed with AlBeMet structures have been environmentally flight-tested.

Manufacturing processes developed on this program and implemented in these products include:

- Development of slurry saw cutting processes for obtaining thin sheet material from HIP (hot iso-static pressed) AlBeMet material
- Development of machining processes for wrought AlBeMet. AlBeMet has proven to be significantly easier to machine than pure beryllium and just slightly more difficult to machine than aluminum. Machining characterization is reported in the attached TR-1374 report (Machining AlBeMet 162 and AlBeCast 910).
- Development of brazing processes for wrought AlBeMet has been very successful. Two sources (Reinhardt of Mountain Home, PA and APL of Fremont, California) of AlBeMet brazing have been developed. AlBeMet braze joint strength is as good as aluminum braze joints.

Processes have been developed for **casting electronic grade AlBeMet 910 parts**. AlBeMet 910 casting were incorporated and tested in the SIRFC LRU-1 chassis. Previously submitted, the TR-1327 report (AlBeMet 910 Characterization Technical Report) provides engineering data for the casting alloy.

- Brazing processes for cast parts have been developed with two contractors (Reinhardt and APL). Brazing has proved to be somewhat more difficult for cast components than wrought components. The coarser Beryllium grain size inhibits braze wetting. Brazing was accomplished by Aluminum coating the AlBeMet surface. Both contractors obtained good braze strength results.
- Machining process development indicates cast material is more difficult to machine than wrought material, however good results are obtained with polycrystalline coated diamond tools. Machining process development is reported in the attached TR-1374 report (Machining AlBeMet 162 and AlBeCast 910)

**Insertion /extraction testing** was performed on simulated Standard Electronic Module (SEM) Frames with various finishes. Results were good showing environmental air and surface readings well within EPA standards.

**Slurry Saw Sheet** processes have been developed to slice sheet material from HIP AlBeMet and E-material blocks. Sheet material is cut in thicknesses ranging from 0.018 inches to 0.625 inches. The process proving to be a very cost-effective means of obtaining sheet material. Operating parameters are described in the previously submitted TR-1313, AlBeMet Sheet Development Technical Report.

**Sheet forming process** development completed. Results are noted in previously submitted technical report TR-1313, AlBeMet Sheet Development.

- Hot (1180°F) forming of extruded and rolled sheet has been successful:
  - 0.09 inch sheet may be bent 90 degrees to a 4t radius in a single step. Bending to a 3t radius is accomplished in a 2-step bend.
  - 0.03 sheet may be bent to 90 degrees to a 3t radius in a single step
  - Attempts to Form at higher temperatures induce incipient melting and porosity of the aluminum matrix.
  - Less expensive 0.03 or 0.09 inch HIP and slurry saw cut sheet material is not formable. The material tends to crack during bending.

**Semi-Solid Metal (SSM) Development** is completed. SSM is a process which molten aluminum and solid Beryllium powder is forced into a mold. SSM develops near net shape parts and promises to be a cost-effective means of fabricating complex parts with minimal machining waste. The process may be used with higher strength heat treatable aluminum alloys, resulting in higher ultimate strengths than is obtained with wrought AlBeMet. The attached TR-1369, Semi-Solid Metal Development Bimodal Distribution, describes the process.

- Aluminum-Beryllium with 30-40% Beryllium formed well.
  - Lower Beryllium content aluminum-beryllium has a higher thermal expansion than AlBeMet with 62% Beryllium. Stresses induced by differences in thermal expansion needs to be considered in assemblies of AlBeMet and SSM Aluminum-Beryllium.
- Aluminum-Beryllium with 50% Beryllium did not form well.

**E-Material (Beryllium-Beryllium Oxide)** microelectronic module housings have been fabricated and tested. TR-1372 (E-Material Development for MCA Housings) describes processes developed for machining, plating and brazing E-material microelectronic multi-component assembly (MCA) housings.

- Experimental radar Transmit-Receive housings were first fabricated, plated and brazed. Hermetic testing is complete with good results. These modules utilize flat E-material bases and are significantly simpler than SIRFC microelectronic housings.
- Complex SIRFC housings have been fabricated:
  - Accuratus, a ceramic machining contractor, successfully fabricated housings with their high spindle speed diamond coated tools with very good tolerance and flatness control
  - Mac-Tek fabricated housings using Electro-Discharge Machining (EDM) and diamond coated milling and drilling tools.
  - Plating reactions with brazing materials have been discovered and have been resolved.

E-material is gold over electroless nickel-plated to provide a surface conducive to brazing and hermetic sealing. During the several braze cycles require to assemble hermetic connectors to the complex SIRFC housing, Geranium (Ge) from the Gold-Ge braze alloy migrates through the gold and reacts to form a brittle compound with phosphorus in the electroless nickel plating. More detail is described in the attached report TM-1331, Analysis of Hermeticity Problems in E-40 MCA Housings with Soldered Ring Frame (Attachment 4). Subsequent parts were successfully brazed by electrolytic nickel plating over the electroless nickel prior to gold plating. The electrolytic nickel isolated phosphorus from the Geranium.

**AlBeMet MCA cases with brazed hermetic connectors has been manufactured and tested. Laser welding processes have been developed to seal covers onto AlBeMet MCA cases.**

- The attached Lawrence Livermore National Laboratory report UCRL-ID_134227 (Laser Welding of AlBeMet) describes processes developed for laser welding AlBeMet
  - AlBeMet to AlBeMet welding has not been successful. The poor welds are attributed to difficulty in controlling weld temperatures so the beryllium phase melts without overheating the lower melting temperature aluminum phase
  - Lawrence Livermore National Laboratory developed a process that yields good Aluminum to AlBeMet welds. This will allow aluminum lids to seal AlBeMet microelectronic MCA housings. Brush Wellman is in discussion with commercial laser welding contractors to commercialize the process.
  - AlBeMet MCA housings have been fabricated and assembled with hermetic connectors. The housings have been successfully exposed to 691 thermal cycles without damage to hermetic seals. Note these housings did not include a laser-welded cover.

**Casting processes for high strength AlBeMet** has been developed for the Raytheon TI TFLIR 49 system. The attached **Raytheon Final Report** describes testing that validates increases in stiffness and decrease in weight by substituting AlBeMet casting alloys for aluminum

- A new casting alloy has been developed:
  - Al-Ni-Cu-Ag-Si alloy
  - 29 KSI yield, 34 KSI ultimate strength
- Resonant frequencies increased 14 to 54%, important for reducing structurally induced line of sight jitter in the optical sensor platform.
- Part weight reduced an average of 24.7%

**TR-1370 (Development and Characterization of Coatings for AlBeMet and E-Materials)** describe processes developed for applying coatings to protect AlBeMet and provide brazing and soldering surfaces for E-Material. The report addresses conversion coating, anodize, nickel plating, BR-127 (organic primer) coatings, gold plating and aluminum plating.

$Be(OH)_2$ corrosion products were found on the surface of AlBeMet structures exposed to high humidity during SIRFC qualification tests. These corrosion products are of concern for environmental health and safety. Corrosion was accelerated in those structures in which brazing flux salts were not thoroughly cleaned from the assembly and leached onto the AlBeMet surface. Reports from Brush Wellman and independent consultants compiled into the attached ITT **Beryllium Aluminum Corrosion Investigation** discuss appropriate coatings and design modifications to avoid these corrosion products. Those recommendations have been incorporated into the SIRFC design.

Humidity and salt fog testing has recently been performed on a SIRFC LRU 3 chassis with the applied recommended coatings. Some corrosion was detected. Test results are still being analyzed. A review by a Beryllium consultant (APL) suggests the cause of corrosion products may be inadequate process control in the application of primer material used to prevent corrosion.

## SUMMARY:

- The infrastructure for Beryllium composite manufacturing has been expanded with several new machining and plating suppliers
- A cost effective process has been developed to fabricate thin sheet AlBeMet and E-Material
- Machining and brazing processes have been developed to support electronic chassis structure fabrication. SIRFC LRU chassis fabricated from wrought and cast AlBeMet parts have been fabricated and qualified
- Hot forming processes for bending rolled sheet material developed
- Alloys and processes have been developed for both electronic grade and structural castings.
- Brazing processes have been developed for cast AlBeMet
- Machining processes have been developed for E-material by two suppliers
- E-material plating reactions with braze materials have been identified and in process of being resolved
- Semi-solid material molding process developed
- Laser welding process for hermetic AlBeMet microelectronic housings developed by Lawrence Livermore Laboratories
- Coating and plating processes developed for AlBeMet and E-Material

## TECHNICAL PROBLEMS:

Several technical issues developed and were addressed as part of this project. They include:

- Machining of cast AlBeMet

  Resolved through the use of diamond coated machine tools

- Machining of E-Material

  Resolved through the use of high spindle speed diamond coated tools and EDM techniques

- Formation of $Be(OH)_2$ corrosion products in a high humidity environment

  Resolved by more thorough cleaning of brazing flux salts from the assembly and better plating and coating. However recent data suggests more stringent process control needs to be incorporated to prevent corrosion in high humidity and salt atmospheres.

- Plating reaction between phosphorus in electroless nickel and gold on E-Material during brazing

  Resolved by barrier coating with electrolytic nickel.

## ATTACHMENTS:

Earlier (February 1999) program reports included the following:

- 2/99 Program Review charts
- TR-1327 AlBeCast 910 Characterization Technical Report
- TR-1313 AlBeMet Sheet Development Technical Report
- TM-1331 Analysis of Hermeticity Problems in E-40 MCA Housing with Soldered Ring Frame

Attached are the following additional reports:

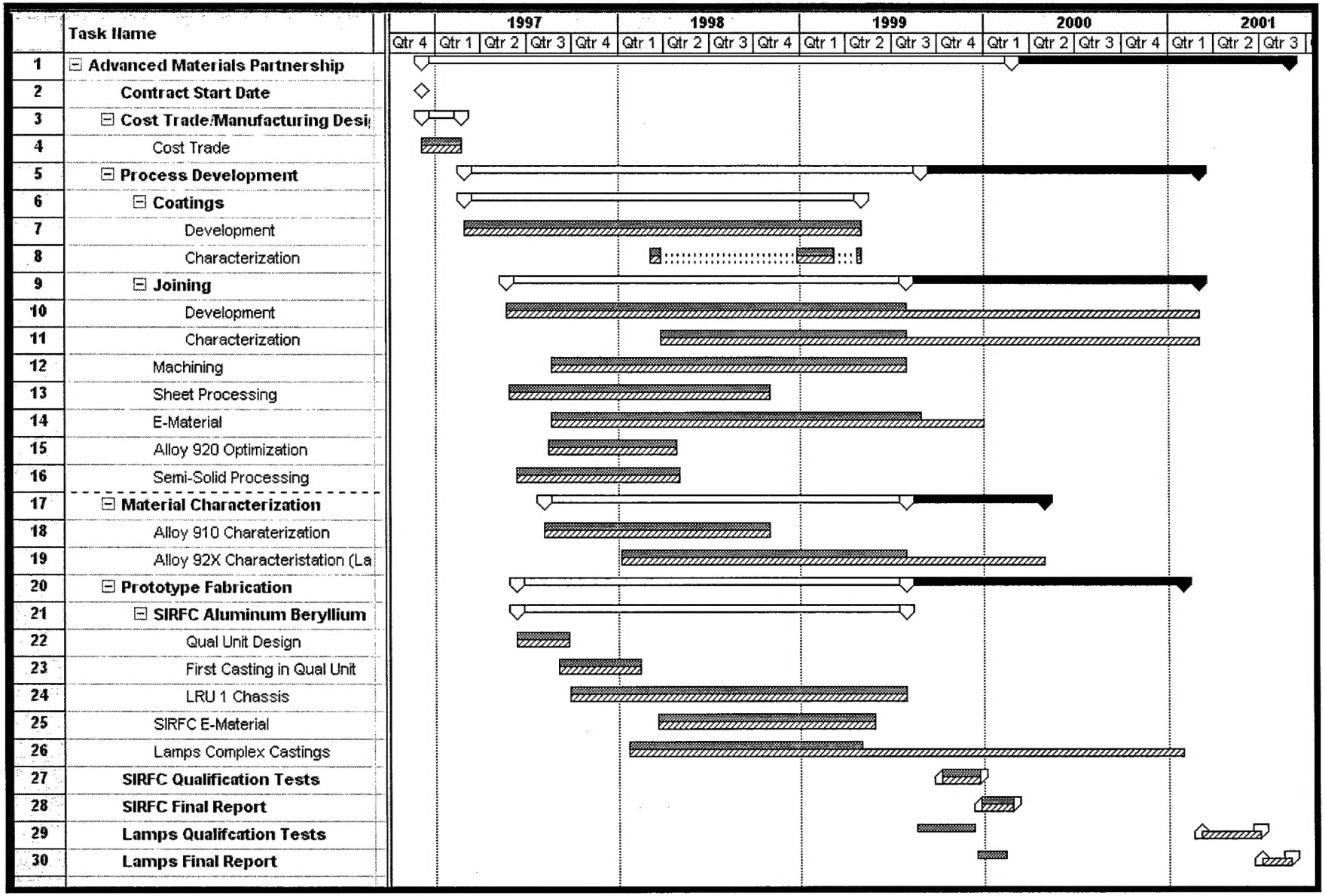
- TR-1374 Machining AlBeMet 162 and AlBeCast 910 January 4, 2001
- TR-1372 E-Material Development for MCA Housings March 20, 2000
- Project Report High Speed Spindle Machining of Be/BeO Composite Feb 18, 2000
- TR-1370 Development and Characterization of Coatings for AlBeMet and E-Materials Oct. 19, 2000
- TR-1369 Semi-Solid Metal Development Bimodal Distribution Feb. 21, 2000
- UCRL-ID-134227 Laser Welding of AlBeMet March 19, 1999
- ITT Advanced Materials Partnership ITT Industries Avionics Engineering Environmental Tests Report Feb. 14, 2000
- ITT Beryllium Aluminum Corrosion Investigation for the Suite of Integrated RF Countermeasures Engineering Manufacturing Development Program Nov. 8, 2000
- TR-1373 Cast Aluminum Beryllium Magnesium Alloy Development Oct. 25, 2000
- Raytheon Final Report Comparison of Aluminum-Beryllium Alloy and Aluminum Alloy Primary Structures in a FLIR Optical System August 27, 2001

## FISCAL STATUS

Amount currently provided on contract: $2,197.959

Expenditures and commits as of the end of fiscal November 2001 are $2,160,130.

# Advanced Materials Partnership



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17 December 2001
DARPA/003

Office of Naval Research
Attn: Mr. Steve Fishman, Code 332
Ballston Tower Centre One
800 North Quincy Street
Arlington, VA 22217-5660

Subject: **Contract N00014-96-C-0171**
Advanced Material Partnership

Reference: CDRL A003, Final Technical Report

Dear Mr. Fishman:

By cover of this letter and in accordance with the terms of the subject contract, ITT is making distribution of the Final Technical Report as follows:

| | |
|---|---|
| Office of Naval Research, Program Manager | 3 copies |
| Director, Naval Research Laboratory | 1 copy |
| Defense Technical Information Center | 2 copies |
| Administrative Contracting Officer | 1 copy |

The DD Form 250 (Z) is provided as an additional attachment to the cover letter for your signature as evidence of acceptance. Please sign and return one copy to the undersigned.

If you have any questions or require additional information please do not hesitate to contact the undersigned at 973-284-4014.

Very truly yours,

Katie Thornton

Enclosures: Final Technical Report – 3 copies